Research on Marketability of GTL (Liquid Fuel from Natural Gas) [1]

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Purpose of This Research

The technological development of GTL has advanced remarkably since the beginning of the 1990s, with its economic viability being greatly improved. Various technological developments must be continued in the future before GTL plants are commercialized and spread widely, and for that purpose it will be essential to clearly envision the marketability of and industrial needs for GTL so that its importance as a fuel can be established. The purpose of this research is to analyze the long-term forecast of oil demand in Asia and its characteristics, to investigate current trends of environmental measures being taken by industrialized countries as well as Asian developing countries, and to study the marketability of GTL and its needs. In addition, this research also aims at exploring a possible role that an option for GTL plays in effective utilization of natural gas, given the fact that there are a number of untapped medium- and small-scale gas fields in Asia, while natural gas from large-scale gas fields justifying LNG projects for Asian markets is in somewhat excess supply.

Conclusion of This Research

1. Demand for oil in Asia is projected to reach 34.99 million B/D in 2020, almost doubling the actual level of 17.58 million B/D in 1996. GTL is believed to be a promising option, having a competitive relationship with an alternative plan for expanding refining facilities aimed at meeting growing demand for oil, especially middle distillates, in Asia in the future.

2. In case quality requirements for gas oil become so stringent that its sulfur content be reduced to 10 ppm or less and also its aromatics content be reduced, full-fledged introduction of desulfurization and dearomatization facilities will be necessary. In this connection, GTL is a promising option to compete with the facility expansion plan referred to above at a time when Asian countries are following industrialized nations in their steps to strengthen environmental regulations in accordance with their economic development stages.

3. If GTL in large demand is to be considered, its entry into the oil market as a substitute for kerosine and gas oil is a promising possibility, given the environmentally friendly quality of GTL. Growing demand for middle distillates anticipated in Asia in the future, coupled with strengthened environmental regulations and increasingly stringent product quality requirements, are expected to serve as a following wind.

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1 This is a gist of the report on the research consigned by the Japan National Oil Corporation (JNOC) in fiscal 1999. We wish to gratefully acknowledge the understanding and cooperation with which JNOC has permitted our publishing this report.

4. From the economic viability standpoint, provided that a low-cost and a small-scale plant is realized, GTL from associated gas has the highest competitive power, followed by GTL from a large-scale gas field, despite the cost of gas transportation from other areas. GTL from medium- and small-scale gas fields in the Asian region is the least competitive, hence the last option.

5. Total demand potential for GTL in Asia is projected to be 500,000 B/D in 2005, which is likely to increase sharply to 4.94 million B/D in 2020 when its supply price is $25/B. At a supply price of $30/B, demand is expected to increase in and after 2015, while at a supply price of $35/B, demand will increase in and after 2020.

6. Required volume of natural gas for GTL production in Asia is projected to be1.8 Tcf in 2005 and 18.0 Tcf in 2020 at a supply price of $25/B; 2.3 Tcf in 2015 and 10.2 Tcf in 2020 at a supply price of $30/B; and 3.7 Tcf in 2020 at a supply price of $35/B. When GTL demand increases, utilization of medium- and small-scale gas fields will obviously become necessary.

7. It will be essential to advance technological development of a GTL plant utilizing natural gas from medium- and small-scale gas fields and to establish its economic viability by the targeted period of 2015-2020. When the global warming due to greenhouse gas emissions is taken into account, CO_2 emissions accompanying the GTL production pose a serious problem. To solve this problem, it is important to develop the CO2 steam reforming process, which leads to recycling of CO_2.

8. When we consider the problem related to energy security arising from emergencies such as the tightening of energy supply due to a rapid increase in demand, environmental problems threatening human health and the ecological system such as air pollution and acid rain and the global warming problem, and when the harmonious achievement of the 3E objectives for the Asian region (stressing the importance of simultaneously achieving economic growth, energy security and environmental protection) is to be established, it is important for Japan to lead other Asian countries in addressing the R&D studies in this area.

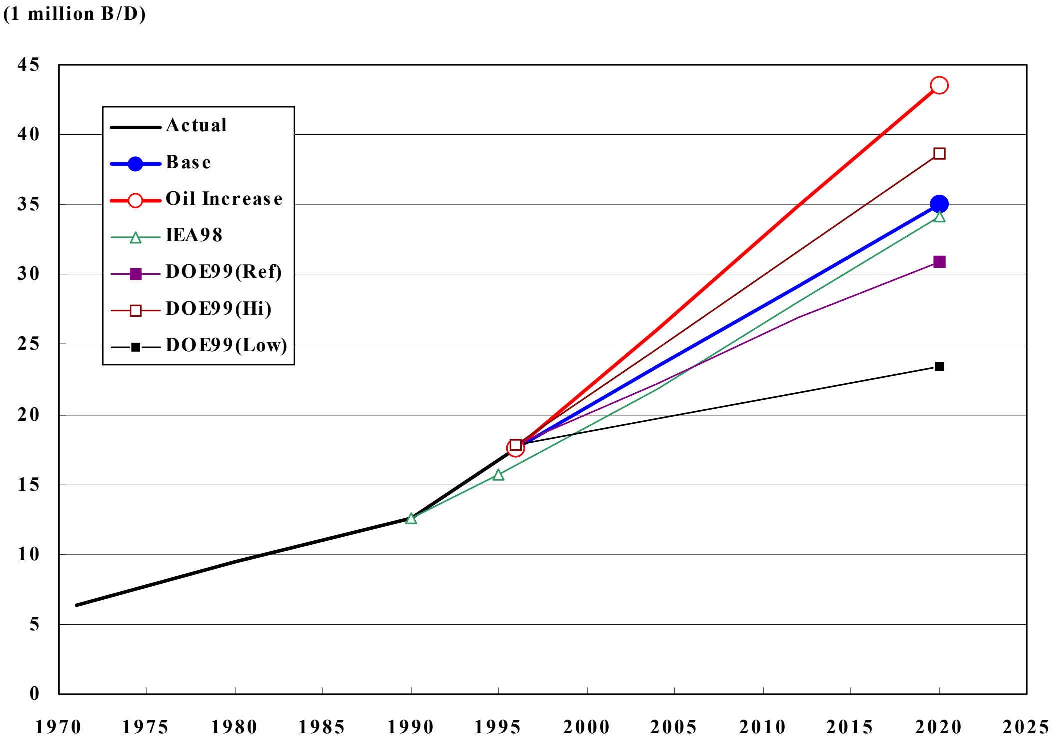
Steady Growth in Oil Demand in Asia from Long-term Perspective ---- Posing a Problem of How to Secure Supply of Middle Distillates

The currency and economic crisis, which hit Asian countries in the summer of 1997, deteriorated throughout the year of 1998. As a result, the rate of increase in energy and oil demand in the Asian region slowed down temporarily, but began recovering its uptrend in 1999. From a long-term perspective through 2020, energy and oil demand are projected to show a steady increase, with the economic crisis not having a large impact on them. In this report, we assumed the base case in which primary energy demand in the Asian region is projected to reach 5.2 billion tons in oil equivalent in 2020 (growing at an average annual rate of 3.8 percent). This projection does not depart greatly from those of the International Energy Agency and the U.S. Department of Energy and hence is not thought to be awkward as a premise for estimating demand for GTL.

The base case incorporates individual Asian countries' government projections as the bases, in which a progressive introduction of non-oil alternative energy sources such as coal and natural gas is called for. Meanwhile, it is generally anticipated that crude oil prices will level off at around $20/B through 2020 on a long-term trend basis. Therefore, there could be a case, as actually witnessed in the 1990s, in which oil's share would not decline as originally projected, or in some countries oil's share would even increase, thus making it necessary to assume in this report a case in which oil demand will increase --- referred to as an "oil demand increase case," vis-a-vis the base case. As illustrated in **Fig. 1**, oil demand in the Asian region is projected to reach 34.99 million B/D in 2020 in the base case, almost double the actual level of 17.58 million B/D in 1996. In the oil demand increase case, oil demand is projected to climb to 43.54 million B/D in 2020, or larger than that in the base case by around 9 million B/D.

A product-by-product demand outlook through 2020 has been worked out against total oil demand projected above, also taking into consideration results of an analytical study by the International Subcommittee. Looking at oil demand by product projected above for the Asian region as a whole in the base case, demand for middle distillates and gasoline will increase to 6.26 million B/D and 3.79 million B/D, respectively, during the 24-year period through 2020, while demand for fuel oil will be limited to 2.41 million B/D, as shown in **Fig. 2**. In the oil demand increase case, demand for oil centering on transportation fuels is projected to be larger in volumes. By region, oil demand in Japan is expected to either level off or increase only slightly, while that in other areas is anticipated to continue showing a steady increase. On a long-term basis, particularly, greater importance will be attached to steady increases in oil demand in China, India and ASEAN nations. When looking at percentage shares of middle distillates, primarily gas oil, it should be noted that they are somewhat on the high side: a 69 percent share in India is followed by a 49 percent share in ASEAN nations and a 48 percent share in ROK.

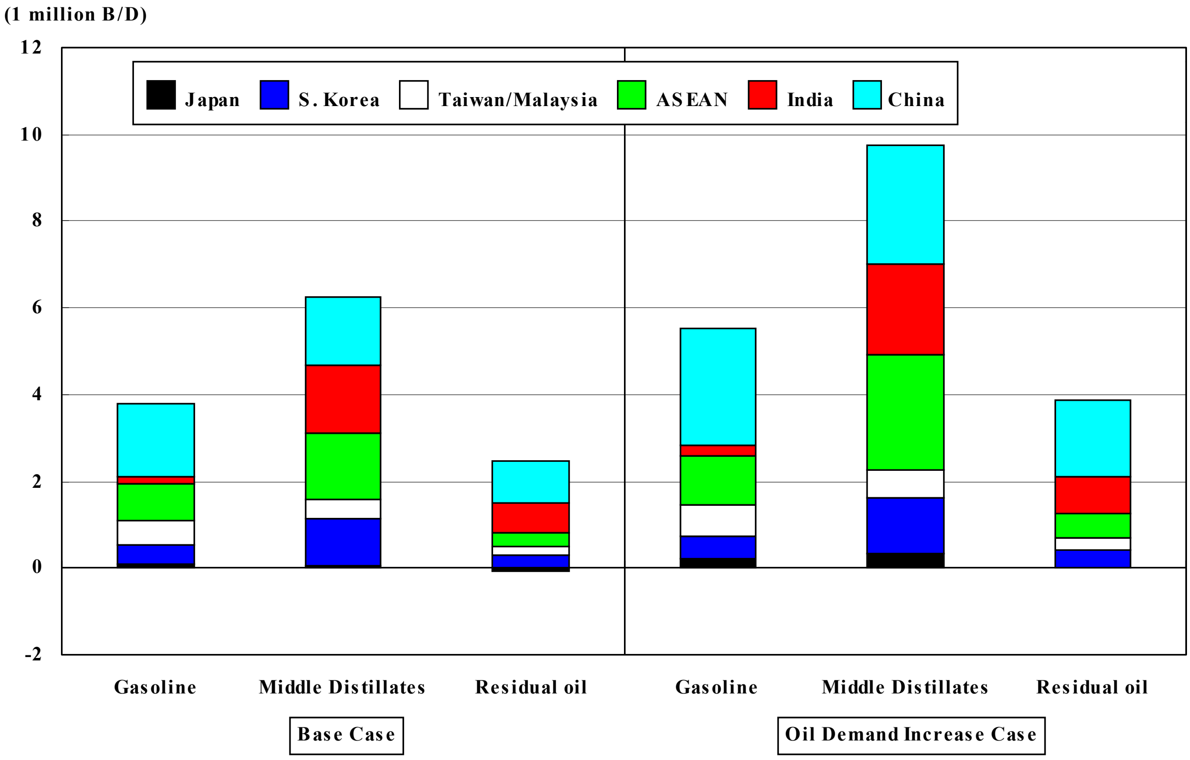
Fig. 1 Prospects for Oil Demand in Asian Region Total up to 2020



(Note) IEA: International Energy Agency, DOE: US Department of Energy

(Source) Analyzed results on this study, US.DOE, "International Energy Outlook, 1999," and IEA, "World Energy Outlook"

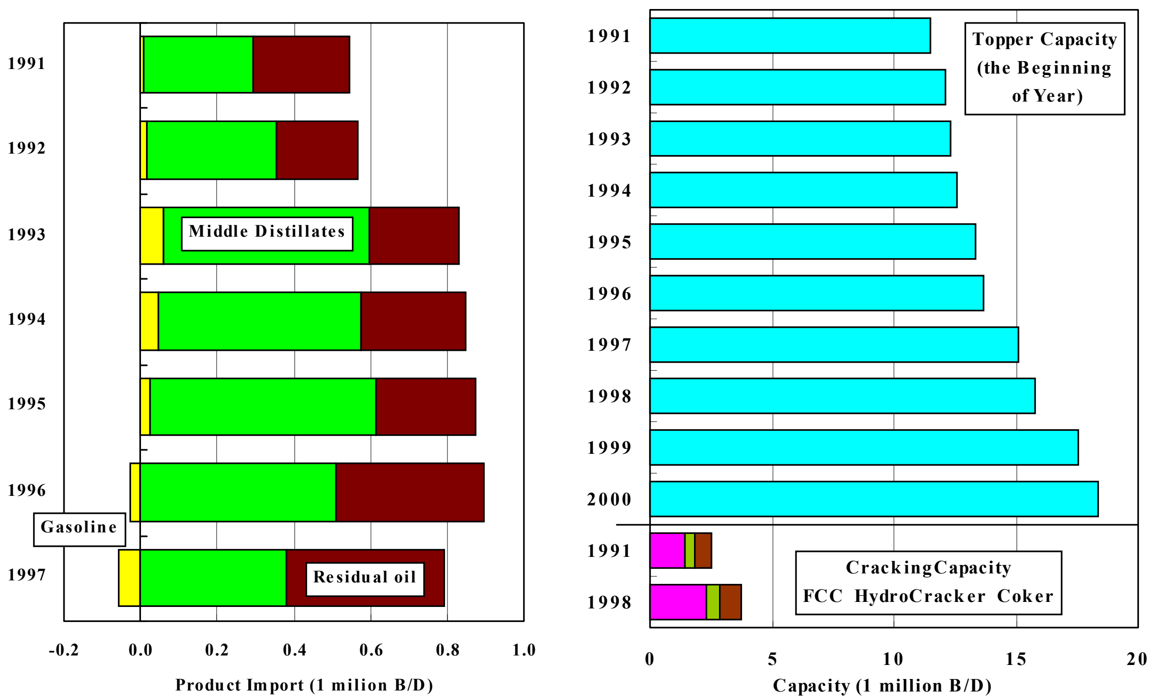
Fig. 2 Increasing Demand Size by Oil Product from 1996 through 2020



(Source) Analyzed Results by This Study

The way how the supply side copes with such an ever-increasing demand for oil is expected to become a crucial problem in the future. In fact, to meet growing demand for oil in and after the second half of the 1980s, increased products imports provided a main pillar in India, China and ASEAN nations, as shown in **Fig. 3**. There are certain limitations, however, to oil products imports and moves to increase refining capacities have gained momentum in ROK, Thailand, China and India. Although the refining capacity increases in Asian devel-

Fig. 3 Countermeasures by Oil Product Import and Refining Plants in Asian Region through 1990s

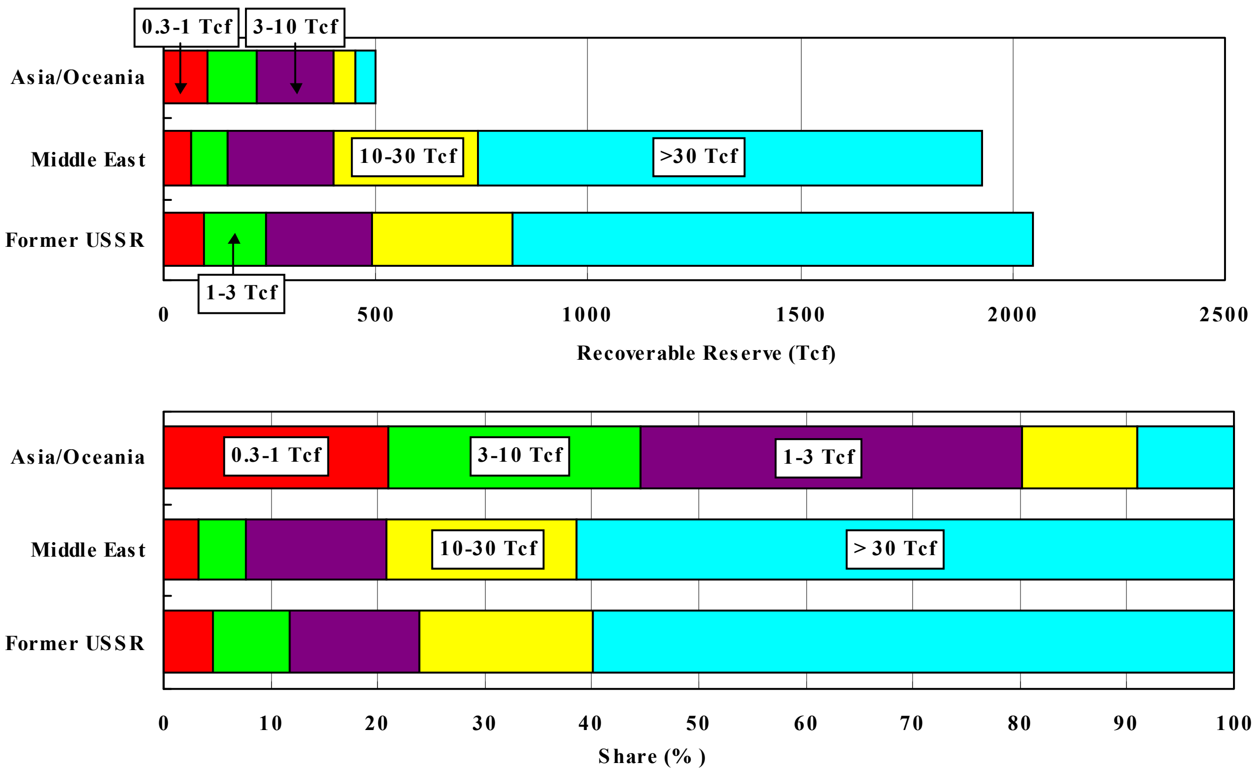


(Source) IEA, "Energy Balances and Statistics in Non-OECD Countries," OGJ, "World Oil Refining Report" oping countries have so far centered on topping plants, with full-scale introduction of secondary processing facilities such as hydrocracking still limited, stepped-up construction of secondary processing facilities so as to meet an increase in refinery crude runs should be an essential issue to be addressed from a long-term perspective through 2020. In this connection, it can be said that GTL offers a promising option as it has a competitive relationship with the Asian oil industry's approach to refining capacity increases aimed at meeting growing demand for oil, particularly middle distillates.

Effective Utilization of Important Medium- and Small-scale Gas Fields in Asia, as Viewed from Standpoint of Economic Viability of GTL

Proved reserves of natural gas in the Asia/Oceania region stood at 550 Tcf (trillion cu ft) in 1998 and the R/P was 37.5 years in 1995 --- somewhat longer than 16.3 years for oil --- due to the limited utilization of natural gas resources. Proved reserves of natural gas have shown a rapid increase since the beginning of the 1980s, discovered primarily in offshore areas --- a characteristic of natural gas resources in the region. Another characteristic of the region's natural gas resources is that they are distributed into a number of medium- and small-scale gas fields. As shown in **Fig. 4**, small-scale gas fields in the order of 0.3-1 Tcf and 1-3 Tcf account for more than 40 percent of total recoverable gas reserves. When gas fields having a scale of 3-10 Tcf are added, they account for as much as 80 percent of the total. Consequently, the effective utilization of medium- and small-scale gas fields has an important bearing in the Asian region and hence is a most suitable natural gas source for production of GTL.

Fig. 4 Distribution of Natural Gas Recoverable Reserves by Size and Supply Sources to Asia

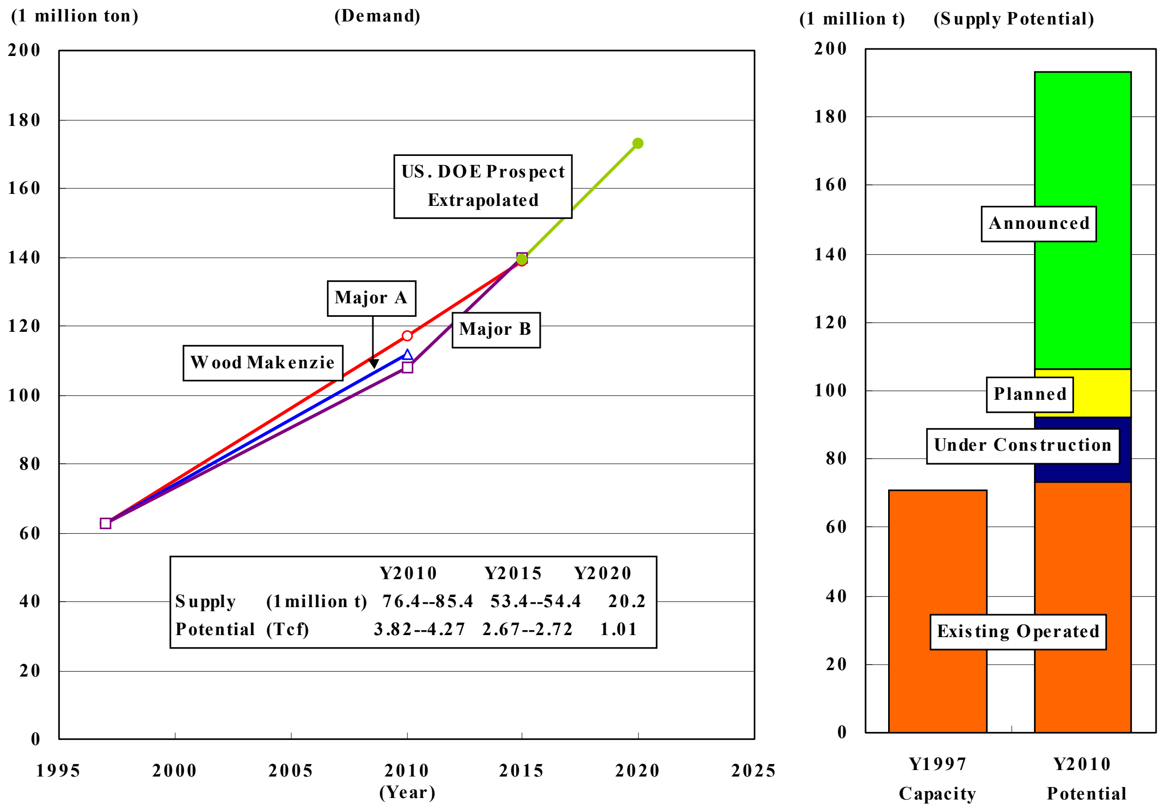


(Source) Prepared from Data in Oil Mining Association, Japan, "Study on Oil and Natural Gas Reserves" (1997)

A close examination of a long-term forecast of LNG demand in Asia vis-a-vis natural gas supply potential for Asian markets reveals a high possibility that a glut in natural gas supply for proposed LNG projects will persist through 2020. Although we cannot make a sweeping statement as new resources are likely to be discovered in the future, a glut in natural gas supply is projected to be 76.4-85.4 million tons (3.82-4.27 Tcf) in 2010, 53.4-54.4 million tons (2.67-2.72 Tcf) in 2015, and 20.2 million tons (1.01 Tcf) even in 2020, as shown in **Fig. 5**. That a glut in supply of natural gas resources for conversion to LNG persists on a long-term basis suggests a move to make use of these surplus resources at an early date for something not competing with LNG. Processing of these resources to produce GTL can be a promising option along this line. In fact, Exxon, BP Amoco, Arco and Sasol are planning to construct GTL plants in Alaska and Qatar. Some experts also point out a possibility of a similar move being made in Sakhalin.

Let us take a look at the rate of natural gas leakage from flare stacks in major oil- and gas-producing countries. In Nigeria, the rate is unusually high at more than 70 percent. Following Nigeria are Saudi Arabia's 15.5 percent and Iran's 10.5 percent. In Asia, Indonesia's rate of flare leakage is 5.5 percent. Mexico and Venezuela are rapidly increasing their flare leakage volumes in recent years. The world's total flare leakage volume totaled 3.5 Tcf in 1984, rising to 4.5 Tcf in 1997. These flare gas leakage into the air mean emissions of greenhouse gases such as CO_2 (carbon dioxide) and CH_4 (methane), which has a larger greenhouse effect than CO_2, making it necessary to take measures to minimize their emissions from the environmental consideration standpoint. The low-value of flare gas has a favorable effect in raising the economic viability and competitive power of GTL plants. In fact, Chevron and Sasol are carrying forward plans to construct GTL plants in Nigeria, taking full advantage of flare gas.

Fig. 5 Surplus in Supply Potential of LNG in Asian Market Expected to Continue up to 2020



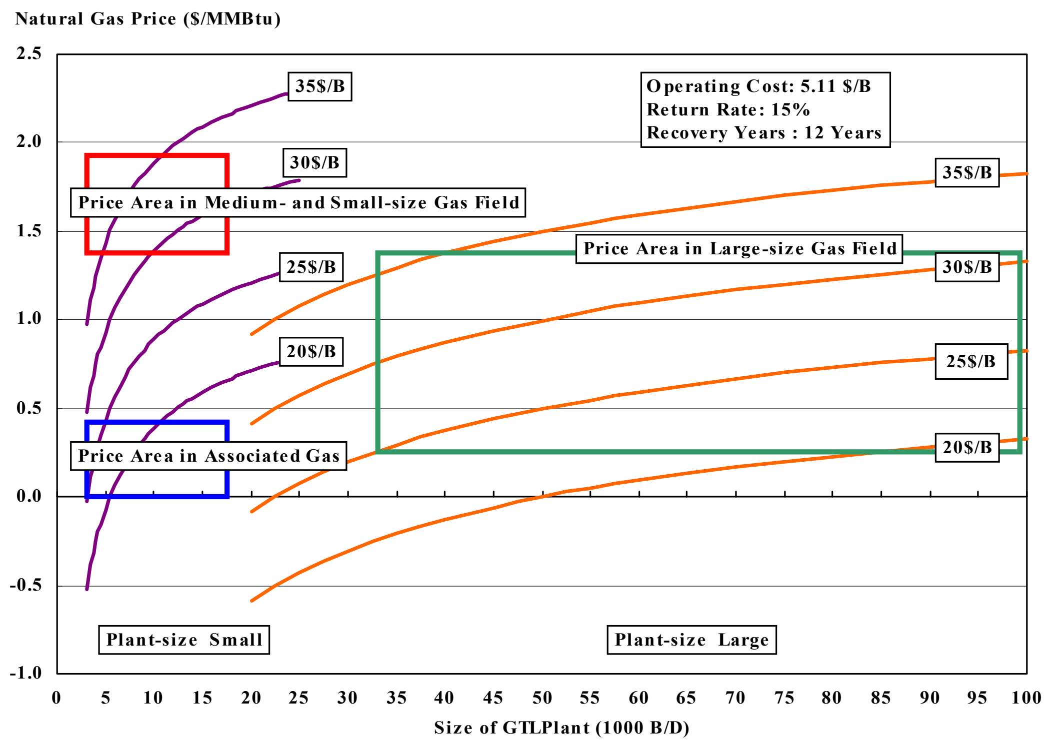
(Source) Prepared from Various Data on Supply and Demand of LNG in Asia Region

The disposal of CO_2 accompanying the GTL production poses a serious problem from the global warming standpoint. The technological development of a process, called the CO_2 steam reforming process, which is still in the research stage, is expected to become the key to the solution of the foregoing problem. In this process, CO_2 is injected into the system along with steam, recycling CO_2 from the Fischer-Tropsch process back into the reforming process, thus restricting CO_2 emissions into the air. In case CO_2 is in short supply for the process, CO_2 from other sources will also be injected, thus affording a powerful means of regulating CO_2 emissions in a broad sense. A close examination of this process reveals that it is the technology leading to the recycling of CO_2 --- the technology indispensable from a long term perspective. Viewed from this angle, the research of the CO_2 steam reforming has an import bearing.

According to an analysis of the economics of GTL plants, the price of GTL from associated gas is estimated at the $20/B level as shown in **Fig. 6**, based on the capital investment cost and the operating expense of $5.11/B, proposed by Syntroleum. When the Exxon-proposed capital investment cost and the operating expense are used as the bases, the price level of GTL from large-scale gas fields will be $20-30/B, while the price level of GTL from medium- and small-scale gas fields is estimated at $30-35/B. If a small-scale GTL plant having a high economic viability is commercialized, GTL supplied by low-cost associated gas generally has the highest competitive power. GTL supplied by gas from large-scale gas fields, even the transportation cost from areas other than the Asian region is added, is considered to come next in its competitive power. GTL supplied by gas from medium- and small-scale gas fields in the Asian region is the least competitive, and hence offers the last option, unless the cost of gas as a raw material drops sharply under some special circumstances.

Outlined above in the order of economics are GTL projects supplied by gas from various sources. The magnitude of flare gas leaked into the air is a mere 1.2 Tcf/year for Asia/Oceania and the Middle East combined

Fig. 6 Supply Costs Based on Price of Feedstock Natural Gas and Size of GTL Plant



(Source) Estimated Results on This Study Based on Data from Various Information Sources and only 4.5 Tcf/year even for the world total. As noted above, a glut in supply of gas from large-scale gas fields aimed at supporting LNG projects is anticipated to persist through 2020: 4 Tcf/year in 2010, 2.7 Tcf/year in 2015 and 1 Tcf/year in 2020 ---rather small and gradually declining, unless new gas fields are discovered.

Japan, U.S. and Europe Showing Stronger Inclination for Introducing “Green Fuels”: Asian Nations Following Suit in Accordance with Their Economic Development Stages

The U.S. and European nations are concerned about an adverse effect of air pollution on human health and the ecological system. The ever-deteriorating air pollution due to NOx and particulate matter (PM) emissions is dictating stringent regulations on automotive emissions --- the main source of air pollution: EU is strengthening restrictions on automotive emissions through EURO III in 2000 and EURO IV in 2005 and the U.S. through TIER 2 in 2004. While there is an antinomic relationship between the automotive fuel efficiency and NOx emissions and between NOx and PM emissions, automotive/engine manufacturers are endeavoring to simultaneously improve the efficiency of combustion in engines, reduce CO and PM emissions and reduce NOx emissions by the after-disposal technology. Since the activity of catalyst used for this after-disposal is badly damaged by sulfur contained in automotive fuels, it is absolutely necessary to reduce the sulfur content of gas oil (or automotive diesel oil) in accordance with the automotive emissions control (EURO IV) in and after 2005.

In the Clean Air Act enacted in 1990, the U.S. has strengthened measures in stages up to 2000 to counter the air pollution by introducing oxygenated gasoline in the winter season, controlling the Reid vapor pressure of gasoline in the summer season, and introducing reformulated gasoline. Moreover, the sulfur content of gas oil was tightened to reduce it to 500 ppm or less. The State of California introduced CARB gasoline, restricting the sulfur content, the aromatics content and the olefin content, while introducing CARB gas oil restricting the sulfur content (to 500 ppm or less) and the aromatics content. Meanwhile, EU decided in June 1998 to reduce the sulfur content of gasoline and gas oil to the "compulsory value" of 50 ppm in 2005, as shown in **Table 1**. This value is so rigid that it is one-tenth the value currently in effect and obligates the oil industry to strictly observe the compulsory value. Other regulatory values of gas oil such as the cetane number and the polycyclic aromatics content in 2005 will be determined, pending the studies of AOP2 (Auto Oil Program 2).

From a long-term perspective, there is a strong possibility that quality regulations of gasoline and gas oil will be further strengthened, as shown in **Table 2**. According to the new quality regulations for gasoline recently published by the U.S. Environment Protection Agency, the sulfur content of 30 ppm or less is required. Automotive manufacturing industries in Japan, the U.S. and Europe also have recently proposed the gasoline quality requirement "Category 4," limiting the sulfur content to 5-10 ppm. Germany has decided to introduce gas oil having the sulfur content of "10 ppm" or less.

In Japan, too, settlements by compromise and rulings in lawsuits related to environmental pollution have urged the government to further strengthen measures to counter the environmental problem. Meanwhile, the Tokyo Metropolitan Government is demanding that prompt countermeasures be taken to solve the problem of black smoke (PM) and NOx emissions from diesel-powered automotive vehicles.

Table 1 Expansion Movement in Quality Standard Regulation of Oil Products in European Countries

		Present Unified Standard	Proposal by EU Committee June 1996		The First Proposal by EU Congress April 1997		Proposal by EU Council June 1997		The Second Proposal by EU Congress Feb. 1998		Final Agree by Congress and Council June 1998	
			2000	2005	2000	2005	2000	2005	2000	2005	2000	2005
Gasoline	RVP Summer kPa	By Class	60	---	60	---	60	---	60	---	60	---
	Aromatics vol %	---	45	---	35	30	42	35	35	30	42	35
	Benzene vol %	5	2	---	1	---	1	---	1	---	1	---
	Olefin vol %	---	18	---	10	---	18	---	14	---	18	---
	Oxygen Content wt %	---	23	---	2.7	---	23	---	2.7	---	2.7	---
	Sulfur Content ppm	500	200	Lower	50	30	150	50	100	50	150	50
Diesel Oil	Cetane Number (min)	By Class	51	---	52	58	51	---	51	58	51	*
	Density at 15 C kg/m2	860	845	---	837	825	845	---	845	825	845	*
	T95 C	370	360	---	350		360	---	360	360	360	*
	Poly-aromatics vol %	---	11	---	6		11	6	11	1	11	*
	Sulfur Content ppm	500	350	Lower	100		350	50	200	50	350	50
Characteristic of Standard		---	Forced	Target	Forced	Target	Forced	Target	Forced	Forced	Forced	Forced

(Note) Quality standard regulations of items with (*) will be announced by EU Committee in the near future.

(Source) IEEJ, "Survey on High-Quality Transportation Fuel" (1998).

Table 2 Long-term Directions on Quality Standard Regulations of Oil Products in Japan, USA, and Western Europe

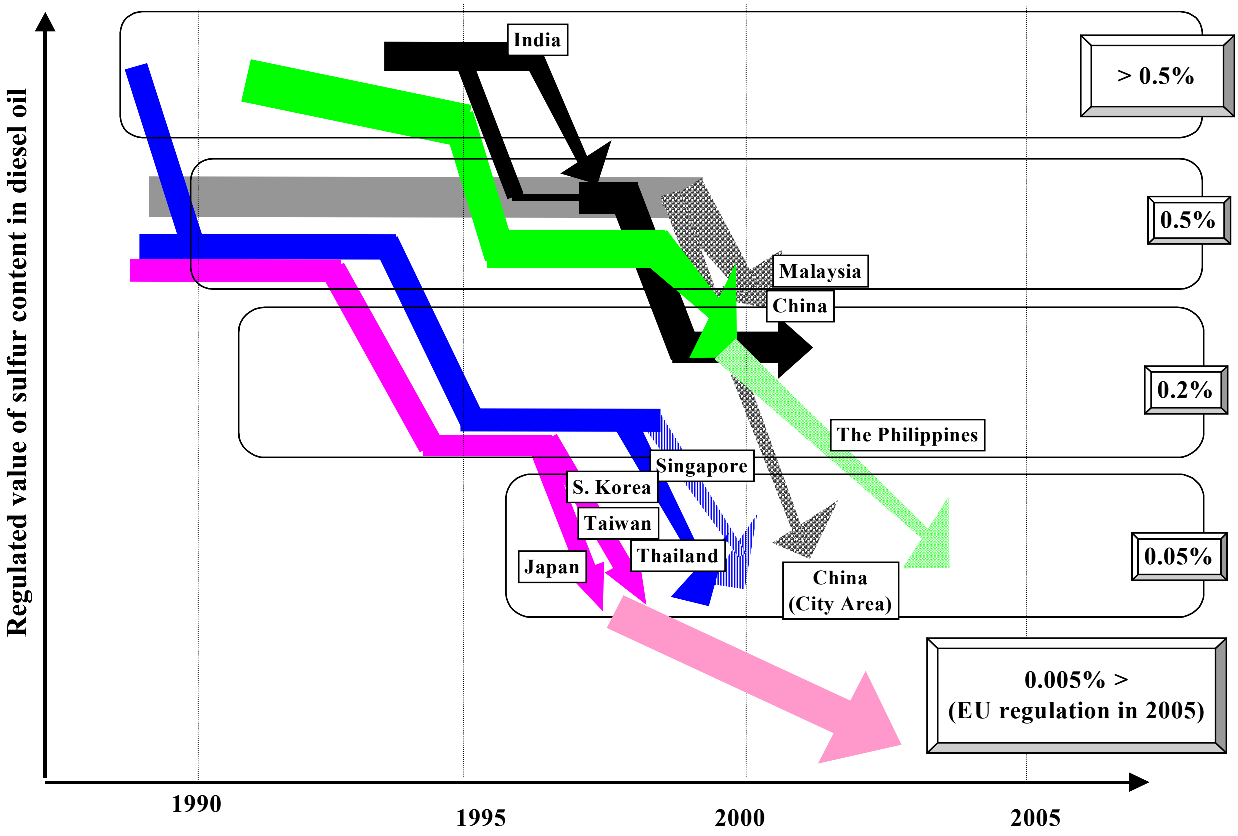
USA	Gasoline	Decision made to tighten sulfur content in stages in and after 2004. Reduce sulfur content of gasoline produced at refineries to 30 ppm (or 80 ppm or less per gallon of gasoline sold at service stations) on average in 2006.	Proposal by EPA
	Gas oil	In preparation for the attainment of the emissions standard under 'TIER2' which will be put into effect in 2004, studies are under way, involving engine manufacturers, manufacturers of equipment for controlling emissions and the oil industry, to work out control values on highly cost-effective engines and fuels. A new control value for gas oil will be published in the spring of 2000.	
Europe	Gasoline	Control values for sulfur content were decided in 1998 as follows: 150 ppm taking effect in 2000 and 50 ppm taking effect in 2005. Aromatics content and olefins content were newly added to regulations taking effect in 2000. Moreover, marketing of leaded gasoline was banned in and after 2000 (with the grace period extended till 2005 in accordance with actual results of implementation).	EU Items Determined
	Gas oil	Control values for sulfur content were decided in 1998 as follows: 350 ppm taking effect in 2000 and 50 ppm taking effect in 2005. The distillation temperature at which 95 percent is vaporized and recovered and the polycyclic aromatics content were added to regulations taking effect in 2000.	
	Both oils	Control values for 2005 enforcement (calling for 50 ppm) will be introduced in 2001 in Europe, or accelerated by four years. Plans are now under way to introduce more stringent control values calling for 10 ppm or less for both gasoline and gas oil. It is proposed by EU member countries that new control values for enforcement in 2005 be introduced in advance and restrictions be further strengthened.	Germany
Japan	Gas oil	The Tokyo Metropolitan Government is concerned about black smoke emissions from diesel-powered automotive vehicles. The oil industry is being asked to reduce the sulfur content of gas oil to a level (50 ppm, to be concrete) – the level at which the technology for cleaning automotive emissions can be practically applied on the part of automotive manufacturers.	Tokyo Metropolitan
	General Trends	Settlement was reached one after another in automotive emissions cases (involving environmental pollution at Nishi Yodogawa in 1998 and that at Kawasaki in 1999). The Kobe District Court, in the January 2000 lawsuit involving automotive emissions on national highways in Amagasaki, ruled for the first time that there was a cause-and-effect relationship between PM in vehicle exhaust gas and the local residents' ailments and ordered the central government and a local expressway corporation to reduce the automotive emissions. (The government is planning to file an appeal to a higher court.)	Pollution Lawsuit
Advanced C.	Both Oils	On the basis of the moves in Europe and the U.S. toward strengthening restrictions on automotive emissions, a revised draft of the world unified fuel products quality standards was added in January 2000 (Category 4), proposing to reduce further the sulfur content in gasoline and gas oil from the current level of 30 ppm to 5-10 ppm.	Car Association in Japan, USA, WE

(Source) Prepared from Various kind of data such as Petroleum Association, Japan "Overseas Oil Related Movements" and Home Page of Tokyo Metropolitan Government.

It will be necessary to newly construct refining facilities to desulfurize and de-aromatize gas oil on a full scale in order to meet the extremely stringent quality requirements to reduce the sulfur content to 10 ppm or less and to reduce the aromatics content to counter the air pollution due to particulate matter (PM) emissions. In this connection, GTL can be a promising option, which will be competitive with the oil industry's approach to construct new refining facilities, calling for prohibitive cost to operate due to consumption of hydrogen in large quantities.

The industry-related environmental disruption and the air pollution are becoming increasingly serious in Asian countries, too, as a result of population growth and the progress in industrialization and motorization brought about by economic development. Moreover, fears are also being expressed about acid rain caused by NOx and SOx emissions due to the burning of fossil fuels, especially coal. Asian countries are now beginning to address environmental problems, making reference to developed countries' approach to environmental problems, though some countries are in different phases from others, depending on their economic development levels. For example, as shown in **Fig. 7**, ROK and Taiwan shifted in the first half of the 1990s in their restrictions on the sulfur content in gas oil from the 0.4-0.5 percent level to the 0.2-0.3 percent level, while Singapore and Thailand showed similar moves after 1995. In Malaysia and the Philippines, studies are under way to strengthen restrictions on the sulfur content. China is also planning to introduce the restriction on the sulfur content of gas oil in urban areas suffering from serious air pollution to reduce it to 0.05 percent --- the same level as currently in effect in industrially developed regions. Similar moves are seen to reduce the lead content in gasoline, eventually to produce unleaded gasoline.

Fig. 7 Changes in Sulfur Content Regulation of Diesel Oil in Asian Countries



(Note) Based on Actual regulation in 1991 and 1995 and planned regulation after 2000

(Source) Prepared from various data

The current fleet of automotive vehicles in Asian countries comprises used and new ones imported from industrially developed countries and those manufactured by relatively young local companies. During the period when the fleet of automotive vehicles in these countries is assumed to increase by the wealthier people's purchase of new cars and the poorer people's purchase of used cars, the use of clean fuels is thought to play a greater role in those countries' measures to counter automotive emission problems rather than the automotive manufacturing industry's efforts to develop new technologies and stepped-up introduction of new cars. Moreover, considering the present situation even in advanced motorized societies in Japan, the U.S. and Europe where further restrictions on automotive emissions are becoming necessary, there is a good possibility that Asian countries will strengthen restrictions on control values for automotive fuels (such as sulfur and aromatics contents), making reference to control values adopted in industrially developed countries.

Characteristics of Environmentally Friendly GTL --- GTL Can Be Used As Promising Substitute for Kerosine and Gas Oil As It Assures Supply to Meet Large-Scale Demand

GTL is manufactured using low-sulfur natural gas as a feedstock, and since the Fischer-Tropsch process is used for synthesizing saturated hydrocarbons, the product is basically very clean, having neither sulfur, nitrogen, aromatics nor heavy metals. Because of its characteristics possessing "harmony with the environment," GTL is expected to have an expanded area of its application in the future. When the GTL fraction is compared with fractions obtained from crude oil, the "gas oil fraction" having a high cetane number with its excellent ignition quality, the "kerosine fraction" having a high smoke point with its excellent burning quality, the "lubricating oil base stock" having a high viscosity index, and the "wax" having a high purity are obtained from GTL, as shown in **Table 3**. The naphtha fraction obtained from GTL, however, has a low octane number and hence is not suitable as a "gasoline base stock" and rather can be a good feedstock for an ethylene cracker.

Table 3 Quality Comparison between Distillate Component of GTL and WTI Crude

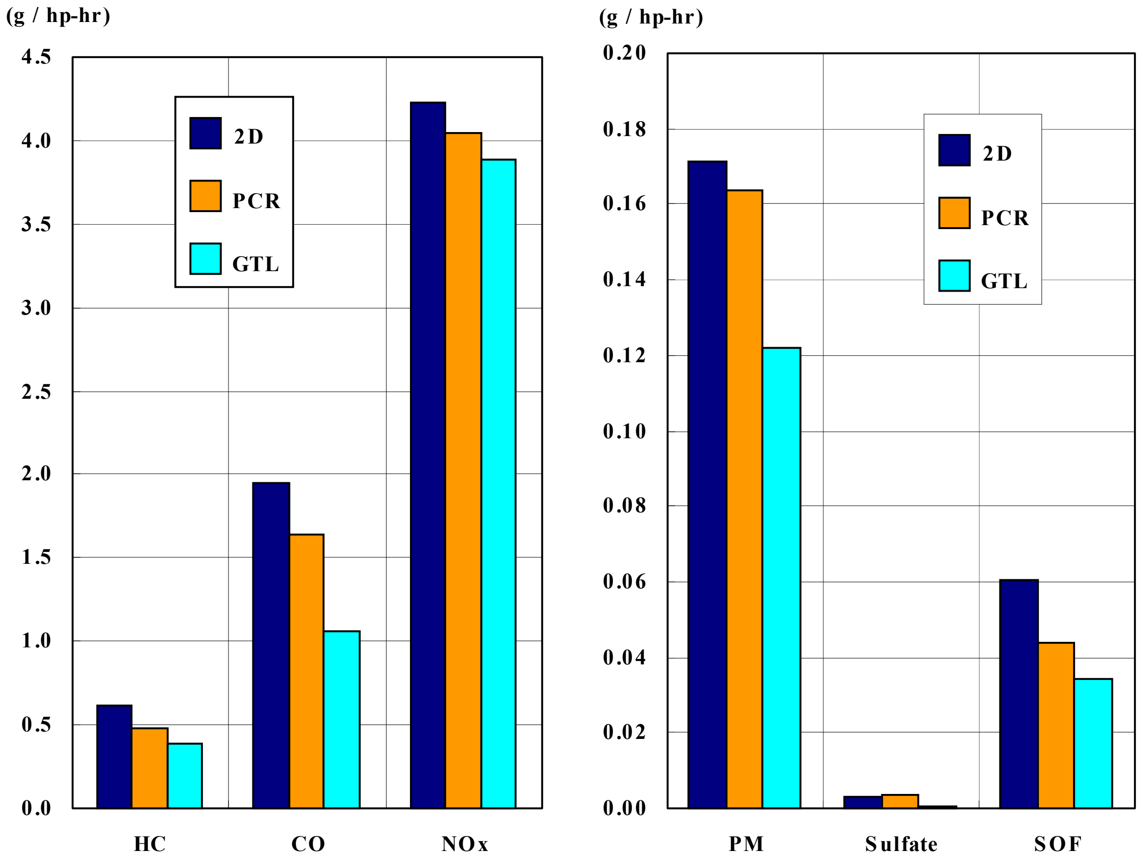
Component	Quality Item	GTL	WTI Crude	Implication
Naphtha	Density, g/ml 60ºF	0.69	0.74	GTL naphtha fraction is not suitable as a reformer feedstock at refineries, but is a good feedstock for ethylene production.
	Sulfur Content, wt%	0	0.07	
	RON Clear	<40	67	
	N+2A	5	51	
Jet / Kerosine	Density, g/ml 60ºF	0.77	0.80	GTL jet/kerosine fraction does not contain aromatics and hence has an excellent smoke point quality.
	Sulfur Content, wt%	0	0.12	
	Smoke Point, mm	45	22	Pending the testing of qualities of GTL jet/kerosine in the future, its use in the aviation industry will be determined.
	Freezing Point, ºF	-53	-53	
Diesel	Density, g/ml 60ºF	0.78	0.84	TL gas oil fraction with its relatively low density tends to worsen its fuel economy rate per km-run for automotive vehicles.
	Sulfur Content, wt%	0	0.37	
	Aromatic Content, LV%	<1	29	
	Cetane Number	>70	56	With its very low aromatics and sulfur contents and high cetane number, the GTL gas oil fraction has a high value as a feedstock for refinery processing.
	Kinematics Viscosity, cSt, 100ºF	2.3	4.0	

(Source) Johannes Thijssen, "Comparison of Exxon, Shell and Sasol Technologies, and GTL Viability," Conference on Monetizing Stranded Gas Reserves '98, December1998, San Francisco, USA.

An operating trouble in a jet plane has a high possibility of leading to an accident directly affecting human lives. It is for this reason that jet fuel is required to have highly stringent qualities such as a) good combustibility, b) high heating value, c) high thermal stability, and d) the absence of foreign matters mixed with the fuel. Jet fuel manufactured from GTL contains little aromatics and hence has good combustibility, good engine startability, and the danger of causing blowout is very slight. The most important property of kerosine for home use is its good combustibility. Compared with naphthenic and aromatic hydrocarbons, paraffinic hydrocarbons have better combustibility. Kerosine manufactured from GTL comprises paraffinic hydrocarbons and is not liable to cause incomplete combustion, since it does not contain smoke-emitting aromatics. In addition, the JIS (Japanese Industrial Standard) for kerosine for home use calls for sulfur content to be 0.008 percent (by weight) or less so that it does not cause indoor air pollution and its combustion gas does not have a bad smell. GTL-derived kerosine therefore is suitable as kerosine for home use.

The GTL gas oil of paraffinic hydrocarbons has a high cetane number and an excellent ignition quality, since it does not contain aromatics. **Fig. 8** compares GTL gas oil with gas oil sold in the U.S. market, showing that GTL gas oil emits 30 percent less particulate matter, 8.3 percent less nitrogen oxides, 46 percent less carbon monoxide, and 38 percent less hydrocarbons --- meaning that use of GTL gas oil is effective in reducing air pollutants in automotive emissions. Combustion in diesel engines, occurring in excess air, produces less CO

Fig-8 Cutting Effect of Air Pollutants in Tail Gas Caused by GTL-derived Diesel



(Note) HC: Hydrocarbon, CO: Carbon Monoxide, NOx: Nitrogen Oxides, PM: Particulate Matter, SOF: Soluble Organic Compounds, 2D: No. 2 Diesel Oil, PCR: Pseudo-CARB Reference
(Source) Jeff Leet, "Potential Application of Fisher-Tropsch Fuels," Conference on Monetizing Stranded Gas Reserves '98, December 1998, San Francisco, USA.

(carbon monoxide) and HC (hydrocarbons) emissions, but emits black smoke and NOx (nitrogen oxides) as a result of diffused combustion. Black smoke includes SOF and sulfates and the reduction in sulfur content of gas oil is required to minimize sulfates which hinder the post disposal of black smoke and NOx. Unless poisoned by sulfur in gas oil, the activity of catalysts designed for cleaning automotive emissions such as nitrogen oxides and hydrocarbons is improved, thus extending the catalyst life over a longer period. In this connection, expectations are high for GTL gas oil which is essentially free of sulfur.

Compared with oil-based wax, wax manufactured by the GTL process (with Nippon Seiro's wax having a trade name of "FT 100") has more excellent qualities, as shown in **Table 4**. Wax having the "Fusing Point of 100 Degree", in particular, can never be manufactured from oil. FT100 has a wide variety of uses. In fact, it is used mostly for hotmelt adhesives, printing ink, face paint dispersant, toner for copying, and reforming agent for various wax. The size of the wax market in Japan is about 100,000 tons (including around 5,000 tons of GTL wax), while that in China is about 1 million tons, or ten times the Japanese market. The market of this magnitude cannot be said too large. Saturated hydrocarbons obtained from the GTL process are also used for a specific purpose as the lubricating oil base stock. Shell's XHVI products are transported from a GTL plant at Bintulu, Malaysia, to the refinery at Yokkaichi, Japan, for final processing to the XHVI base oil, from which various products are manufactured. Optimum additives are then blended with these products so that they meet many different uses as high-quality lubricants in a wide variety of areas.

As outlined above, products such as kerosine and gas oil manufactured from GTL have environmentally friendly characteristics as they contain little sulfur and aromatics. Moreover, saturated hydrocarbons (paraffinic hydrocarbons) obtained from GTL give wax and lubricating oil such qualities that cannot be developed otherwise, thus producing goods of high value added and of high profitability. Demand for these goods of high value added, however, is limited. If GTL in large demand is to be developed, it appears advisable to have GTL enter

Table 4 SpecialCharacteristics inWax and Its Specific Use Adding Higher Value

General characteristics:	**In comparison with oil-based wax:**
Extremely small percentage of volatile component	Higher fusing point
Low fusing viscosity	Smaller penetration and high hardness
Highly moistureproof and waterproof	Lower viscosity for its higher fusing point
Tasteless and odorless	Larger latent heat
Suitable uses for FT100:	
Hotmelt adhesives ----- to reduce viscosity and improve wettability	
Various kinds of polish ----- to harden painted film and reduce stickiness	
Printing ink, face paint dispersant ----- to give ink resistibility to abrasion	
Resin lubricant ----- effective as external lubricant	
Rubber antioxidant ----- to give excellent ozone cracking prevention effect under high temperatures	
Various wax reforming agents ----- to give hardness and improve blocking temperature	
Crayon ----- to give hardness	
Roast wax ----- to give hardness	

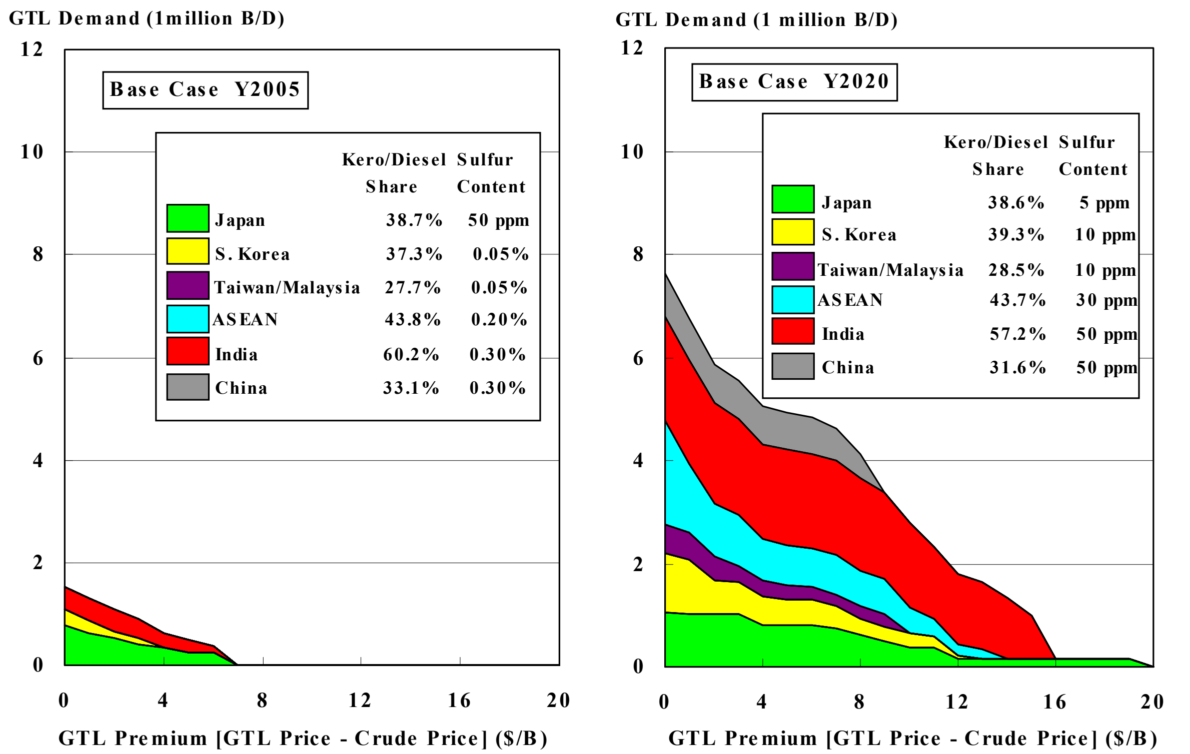
(Source) Prepared from interview results to the related company the market as a substitute for kerosine/gas oil, taking advantage of its having environmentally friendly characteristics. Increasingly stringent environmental regulations and ever-increasing demand for middle distillates anticipated in Asian markets in the future are expected to serve as a following wind to that effect.

Hoped-for Marketability of GTL in Asia: Improvement of Its Economic Viability Holds Key to Successful Utilization of Medium- and Small-scale Gas Fields

We have made an analysis, using the petroleum refining model, to find out what GTL supply patterns should be adopted by varying GTL supply prices against oil demand anticipated in 2005, 2010, 2015 and 2020 in six countries/regions of a) Japan, b) ROK, c) Taiwan and Malaysia, d) ASEAN nations (excluding Malaysia), e) India and f) China. It was assumed that environmental and product quality regulations in each country/region follow those in industrially developed countries in accordance with the economic development stage for each country/region.

Examining the approach by each country/region to the GTL processing vis-a-vis facilities, it was found out that there were great variations among them in the necessity of GTL processing, depending on the rate of growth in oil demand, oil demand mix characteristics, and the extent to which environmental and product quality regulations are being strengthened. Premiums on GTL prices vis-a-vis crude oil prices are at least $6-7/B and could rise to more than $15/B when facility requirements become stringent. This means that GTL has a wide demand potential. At the price level of $25/B, total GTL demand potential in Asia is projected to be 500,000 B/D in 2005, which is likely to increase sharply to 4.94 million B/D in 2020, as shown in **Fig. 9**. At the GTL price level of $30/B, there will be some demand potential in 2010, but demand is fundamentally expected to increase in and after 2015. When priced at $35/B, GTL demand potential cannot be expected before 2020.

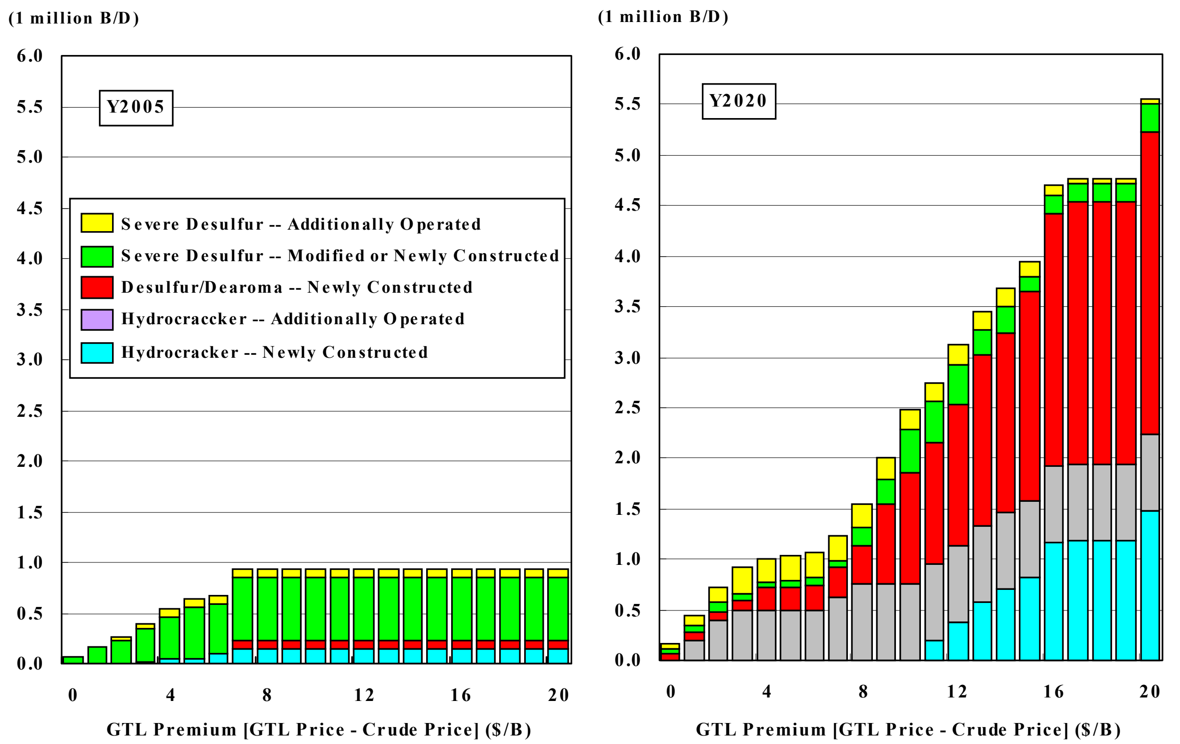
Fig. 9 Changes in Demand Potential of GTL in Asia Region (Base Case)



If GTL is not opted in 2005 in the base case, it will be necessary to remodel and/or newly construct gas oil deep desulfurization facilities, newly construct desulfurization and dearomatization facilities, and newly construct hydrocracking facilities --- totaling around 1 million B/D --- in Asia, as shown in **Fig. 10**. When increasingly stringent environmental and product quality regulations are enforced in Asian developing countries in 2015 and 2020, full-scale introduction of desulfurization and dearomatization facilities and stepped-up construction of new hydrocracking facilities will be necessary --- totaling around 2.5 million B/D in 2015 and around 5.0-5.5 million B/D in 2020, in case GTL is not opted. Remodeling and/or new construction of deep desulfurization will be necessary to upgrade the gas oil qualities. If these facilities are insufficient, desulfurization and dearomatization must be introduced on a full scale. Hydrocracking is necessary to convert fuel oil to middle distillates for increased production of the latter. Construction of these facilities entails a heavy fixed cost burden and consumption of hydrogen in large quantities increases variable expenses. To what extent the premium on GTL can be raised depends on the magnitude of these cost and expenses. In and after 2015, introduction of both desulfurization/dearomatization and hydrocracking will be necessary in some areas, in which case the upper limit of the premium will increase from $12/B in 2015 to $16/B in 2020.

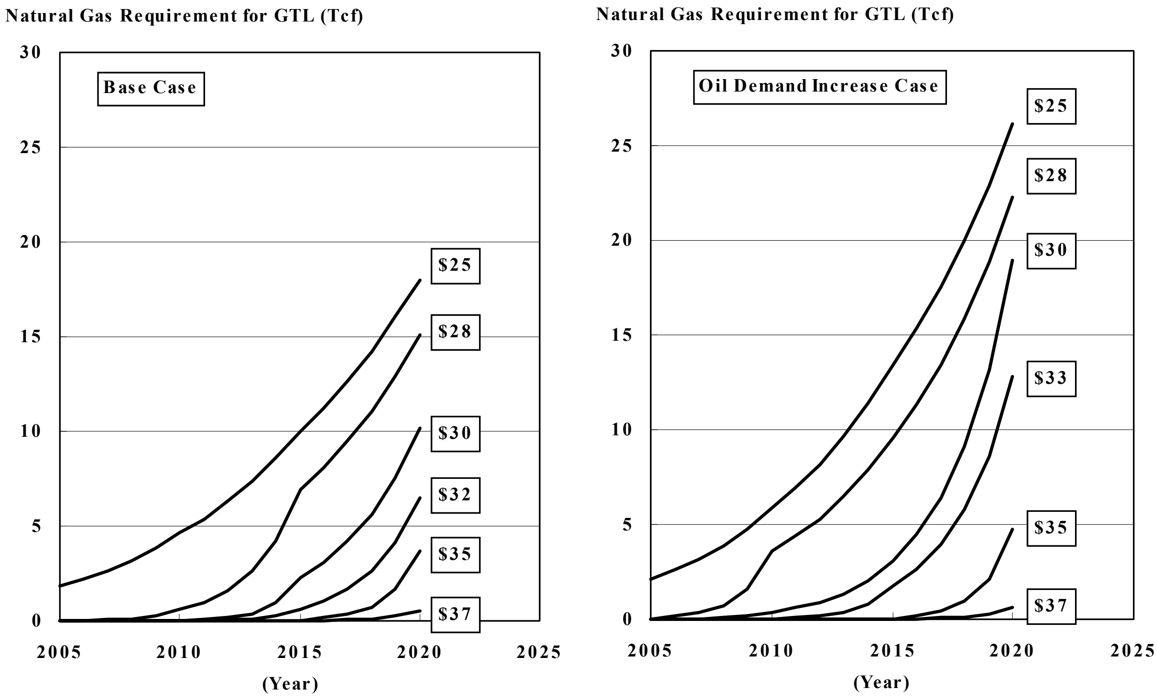
The volume of natural gas required to produce one barrel of GTL is 10,000 cf. If GTL can be supplied at $25/B, the volume of natural gas required to produce GTL for Asian markets is projected to be 1.8 Tcf in 2005, 4.6 Tcf in 2010, 10.0 Tcf in 2015 and 18.0 Tcf in 2020, as shown in **Fig. 11**. In case the price of GTL rises to $30/B, the volume of natural gas required will be 2.3 Tcf in 2015 and 10.2 Tcf in 2020; at $35/B the volume required will be 3.7 Tcf in 2020. From the standpoint of economic viability of GTL, GTL from the flare gas comes first, followed by GTL from large-scale natural gas fields which can be developed into LNG projects, and thirdly by GTL from medium- and small-scale natural gas fields in Asia. The scale of supply in the first two

Fig. 10 Changes in Refining Plants Additionally Operated, Modified or Newly Introduced (Base Case)



(Source) Analyzed results in this study

Fig. 11 Natural Gas Requirement for GTL Production in Each Year from 2005 through 2020



(Source) Analyzed results in this study

options above, however, has certain limitations, thus obviously leading us to the necessity of using natural gas from medium- and small-scale gas fields, in case demand for GTL becomes large enough to justify the third option.

When deciding on constructing a GTL plant, there should be a prospect for securing the feedstock to cover the whole plant life period. When the volume of natural gas required for each GTL plant coming on-stream through 2020 is added, the cumulative total reaches 451 Tcf at the GTL price of $25/B, exceeding the remaining proved recoverable natural gas reserves in the Asia and Oceania region totaling 343.5 Tcf. The cumulative total natural gas requirements reach 254 Tcf at the GTL price of $30/B and 92 Tcf at the price of $35/B. Consequently, the utilization of natural gas resources widely distributed in medium- and small-scale gas fields in Asia is absolutely necessary, thus making it important to develop technologies to realize it.

Technological Developments Aimed at Establishing Economic Viability of GTL Play Vital Role in Achieving Harmony among Asia's 3E Objectives

Of technological developments for the GTL process, large-scale GTL plants, for which supply of feedstock gas from large-scale gas fields is required, reduce the construction cost and are being materialized on a commercial basis by the majors probably by 2005-2010. As for small-scale plants relying on medium- and small-scale gas fields, meanwhile, it will be necessary to further promote technological developments in the future to clearly establish their economic viability, though some technological innovations are under way. Although GTL based on large-scale gas fields that can be developed into LNG projects is of course an important option, considering the GTL supply in Asia, it will be indispensable to utilize medium- and small-scale gas fields in Asia in view of GTL demand potential in Asia, provided that it is economically viable. For this purpose, while attempting to make GTL plants small-scale ones, we must see to it that GTL plants have economic viability in their competition with other energy sources even under circumstances where the feedstock gas must be assessed at fairly high price levels.

Given such long-term issues as ever-growing energy demand and ever-deteriorating environmental problems in Asia as noted above, it will be an essential task to be addressed in the energy field to promote technological development of GTL plants relying on medium- and small-scale gas fields in Asia and to establish their economic viability in and after 2010, say, during the period from 2015 to 2020. Japan should lead other Asian countries in tackling this task. When promoting the technological developments, it should not be forgotten that thoughtful consideration is given to global warming problems, as mentioned later.

Although this report does not necessarily show a detailed analysis, energy supply in Asia is not showing an increase rapid enough to satisfy fast-increasing energy and oil demand in the region, resulting in Asia's growing reliance on energy supply from outside sources. Asia's reliance on Middle Eastern oil, in particular, has been increasing remarkably since the beginning of the 1990s, casting a cloud over the energy security problem of the Asian region. With Asia's growing reliance on Middle Eastern crude in the 1990s, Middle Eastern crude oil prices for the Asian market have remained at levels \$1.0-1.5/B higher than those for the European and U.S. markets. Since Asian LNG and coal prices are either linked with crude oil prices or determined in reference to crude oil prices, energy prices in Asia are believed to be set at relatively higher levels. This problem is believed certain to become an important issue to be closely examined when the international competition intensifies with European and U.S. markets. In order that Asia will not be exposed to an energy environment in which unduly high energy prices prevail, it will be essential for Asia to develop its bargaining power in various ways to such an extent that Asia's growing reliance on Middle Eastern crude can be held in check. While it remains to be seen to what degree GTL supply potential of medium- and small-scale gas fields in the Asian region turns out to be, the GTL option should be fully exercised as a means of cultivating Asia's bargaining power.

Disposal of CO_2 emitted simultaneously with GTL production is an important subject, when considering the global warming problem. To solve this problem, development of the CO_2 steam reforming process can provide a vital clue. From the standpoint of achieving the stabilization of greenhouse gas emissions in accordance with the target established at the United Nations Framework Convention on Climate Change, this process is expected to lead to development of the CO_2 recycling technology --- the technology which will be indispensable from a long-term perspective. Although this process is still in the basic R&D stage, it must be developed to promote commercialization of GTL plants and also to establish the CO_2 recycling technology on a long-term basis. At present, although natural gas which is easy to handle is used as a feedstock for development of the process, there is a possibility in the future to develop a process of synthesizing liquid fuel, using steam as a source of manufacturing hydrogen in reference to the gasification of coal, while restricting CO_2 emissions.

Judging collectively from what is outlined above, the technological development of the GTL process, giving due consideration to environmental problems, is an area where vigorous efforts should be made in the future. When the global needs for the establishment of CO_2 recycling technology --- required for effective utilization of fossil fuels such as coal, a resource abundantly available, oil and natural gas --- are taken into consideration, it will be an important and extremely significant idea to afford public support to the technological development until it becomes fully competitive in economic terms on the market. With a view to achieving harmonious realization of the 3E objectives of Asia, including the energy security problem of how to face the tightening supply of energy and oil vis-a-vis the rapidly growing demand and other emergencies, and environmental problems such as the ever-deteriorating air pollution, acid rain, and the global warming which are threatening human health and the ecological system, it is extremely important that Japan takes the initiative to be in charge of R&D studies of these fundamental technologies toward their early commercialization.